Breeding Progress for Potato Chip Quality in North American Cultivars

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ABSTRACT

Forty-four potato cultivars, released in the period between 1876 and the present were grown concurrently in field trials, stored simultaneously in three different environments, then evaluated for chip quality. They represented cultivars historically used and/or bred for potato chip production. Quality factors measured were tuber solids, chip color, reducing sugar levels, sucrose levels, and percent of defect-free chips. Tuber solids tended to increase in the late period cultivars, but trends were erratic. The release of Lenape marked the beginning of an increase in tuber solids that has continued to the present. There was a significant trend for lower reducing sugars and better chip color that corresponded to increasingly later cultivar release dates. Since about 1960, progress toward lower reducing sugars and better chip color has been constant, regardless of whether tubers were stored at 4.4 C, stored at 4.4 C and reconditioned, or stored at 10 C. Late period cultivars tended to have a greater percentage of defect-free chips in comparison to those released earlier, with most of the improvement coming during the last few years. This study provided evidence that potato breeders have made significant progress in developing cultivars with good chip quality. Evidence was also found that Lenape was a landmark cultivar and has been an important contributor to the observed breeding progress.

RESUMEN

Cuarenta y cuatro cultivares de papa liberados entre 1876 y la actualidad fueron plantados al mismo tiempo en ensayos de campo, luego almacenados simultáneamente en tres diferentes ambientes, y posteriormente evaluados para analizar la calidad de las hojuelas. Estos representaron cultivares históricamente empleados y/o mejorados para la elaboración de las hojuelas de papa. Los factores de calidad que se analizaron fueron los sólidos del tubérculo, el color de las hojuelas, los niveles de los azúcares reductores y la sacarosa y el porcentaje de hojuelas libres de defectos. Los sólidos del tubérculo tendían a aumentar en los cultivares de períodos tardíos; sin embargo, las tendencias fueron inconstantes. La liberación de "Lenape" marcó el inicio de un aumento en los sólidos de los tubérculos que ha continuado hasta la actualidad. Hubo una tendencia significativa para azúcares reductores más bajos así como un mejor color de hojuela que correspondió a las fechas progresivamente más tardías de la liberación de los cultivares. Desde 1960, aproximadamente, el progreso hacia azúcares reductores más bajos y un mejor color de hojuela ha sido constante, a pesar de que los tubérculos fueran almacenados a 4.4 C, almacenados a 4.4 C y reacondicionados, o almacenados a 10 C. Los cultivares de períodos tardíos tendieron a tener un mayor porcentaje de hojuelas libres de defectos en comparación con aquellos cultivares liberados más temprano, y la mayoría del mejoramiento se ha dado en los últimos años. Este estudio proporcionó evidencia de que los mejoradores de papa han obtenido progresos significativos en el desarrollo de cultivares con buena calidad en las hojuelas. También se encontró evidencia de que Lenape fue un cultivar memorable y ha marcado una importante contribución al progreso observado del mejoramiento.

INTRODUCTION

Potato chips were first made in the middle of the nineteenth century (Talburt, 1975). They were primarily pro-

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Abbreviations: FW = fresh weight

duced in the home until around 1930 when small potato chip companies emerged. During World War II, potato chip consumption grew rapidly and the industry emerged as a major user of potatoes. Ten percent of the potatoes produced in North America in 1995 were processed into chips (National Potato Council, 1995).

The production quality of potato chips requires stringent control measures and selection of the appropriate cultivars is one method used to meet established specifications (Gould, 1980). During the early years of chip manufacturing, cultivars bred specifically for potato chips were not available, so processors used the best existing cultivars that had been bred for other purposes. As the industry became better established, varieties were developed specifically for production of potato chips (Thompson, 1975). This led to the release of several widely used cultivars during the period extending from 1960 to 1970. Among these were Superior (Rieman, 1962), LaChipper (Miller et al., 1963), Monona (Stevenson et al., 1965), Lenape (Akeley, et al., 1968), Norchip (Johansen et al., 1969), and Shurchip (O'Keefe, 1970). Chip cultivar development continues to be an important goal of breeding programs, and efforts have increased to release cultivars that will produce light-colored chips directly from cold (4 - 6 C) storage (Pavek, 1987; Thill and Peloquin, 1995). This has led to wider use of wild species germplasm that possesses exceptional chipping traits (Plaisted and Hoopes, 1989).

Quality traits important for cultivars used in potato chip manufacturing include high dry matter, low sugars, and freedom from defects (Dale and Mackay, 1994). Chip defects can result from several external and internal problems including growth cracks, hollow heart, heat necrosis, mechanical injury, greening, and tuber rot. In addition to internal quality traits, chipping potatoes usually have an appearance typified by round shape and thin, smooth skin.

A recent publication by Douches et al. (1996) provided evidence that progress has been made in breeding potatoes for many important characteristics, including appearance, chip color, and specific gravity. Cultivar use patterns support the idea that significant progress has been made in developing superior cultivars. Few cultivars released before dedicated chip cultivar breeding are still used for chip manufacturing. In spite of the evidence, a direct comparison of cultivars is necessary to document breeding progress. This study provides a comprehensive examination of historical improvement in the quality traits of North American cultivars used to produce potato chips. This paper complements and extends the findings reported in the 1996 publication of Douches et al.

MATERIALS AND METHODS

Forty-four cultivars were chosen for this study, based on their having met one of two criteria: 1) they have historically been used to provide a significant amount of raw product for chip production, or 2) they were cultivars reported by their respective breeders to be released specifically for chip production. Some cultivars matching these criteria were not included in the study due to the unavailability of seed. Three recently developed, but unreleased breeding selections (referred to as cultivars to simplify the text) were included because of their purported cold chipping ability. A list of the selected cultivars, their parentage, and release dates are presented in Table 1.

When available, five or more cultivars were included from each decade beginning with the release date of the oldest cultivar. This was possible with the decade beginning in 1940 and later decades, but not earlier because many cultivars released during that period have become extinct. When more than five cultivars from a decade were available, they were ranked by commercial importance, and the least important ones eliminated. When this process did not clearly delineate choices, extra cultivars were retained.

Seed tubers of the 44 cultivars were obtained from Alvin Reeves, University of Maine; Joseph Pavek, USDA/ARS, Aberdeen, Idaho; Florian Lauer, University of Minnesota; and David Holm, Colorado State University. In 1994, all 44 cultivars were planted, May 2, on the Aberdeen Research and Extension Center, in a randomized complete block trial with four replications. Single row plots were 6.1 m long and 0.9 m wide. Plants were spaced 25 cm apart within the row. The trial was treated as a full-season crop and managed typically for the area. Throughout the season plots were inspected, virus infected plants removed, and plots were treated with insecticides to help prevent virus spread so tubers from the plots could be used as seed in 1995. Vines were killed September 1 and plots harvested September 28. Tubers from each plot were graded, weighed, and sampled for chip quality evaluations.

Duplicate trials were grown at two locations in 1995, on the Aberdeen Research and Extension Center, and on the farm of Mr. Berkeley Wray, seven miles west of Blackfoot, Idaho. The design and management of the trials were the same as in 1994. Planting, vine killing, and harvest dates for the Aberdeen trial were April 26, September 7, and September 22, respectively. The Blackfoot trial was planted May 25 and harvested September 27. The vines were artificially killed by removal of the vines, but no date was recorded. Cold, wet

TABLE 1.—*Forty-four cultivars historically used and/or bred for chip production, their parentages, and release dates.*[1]

Cultivar	Parentage	Release Date[2]
Irish Cobbler	Unknown	1876
Russet Burbank	Sport of Burbank	1876
Katahdin	USDA S40568 x USDA S24642	1932
Chippewa	USDA S40568 x USDA S24642	1933
Houma	Charles Downing x Katahdin	1936
Sebago	Chippewa x Katahdin	1938
Erie	USDA S45146 x Earlaine	1942
Menominee	Richter's Jubel x USDA S44537	1944
Teton	USDA S45146 x Earlaine	1946
Kennebec	B127 x USDA X96-56	1948
Yampa	USDA X245-186 x Katahdin	1949
Pungo	USDA X96-44 x USDA X528-170	1950
Merrimack	USDA X96-56 x Saranac	1954
Saco	USDA S41956 x USDA X96-56	1954
Plymouth	Mohawk x USDA X96-56	1955
Tawa	B76-23 x B595-76	1956
Haig	Cayuga x MN43	1957
Superior	MN59.44 x USDA X96-56	1961
LaChipper	Cayuga x Green Mountain	1962
Monona	B1268-46 x B1299-15	1964
Lenape (B5141-6)	USDA S47156 x B3672-3	1967
Norchip	ND4731-1 x M5009-2	1968
Shurchip	Neb.226.49-1X x Neb.25.47-7X	1969
Raritan	F45019 x SSRPB 834C	1970
Mirton Pearl	Mira x F5318	1975
Atlantic	Wauseon x B5141-6 (Lenape)	1976
Tobique	F45019 x Cariboo	1977
Trent	Nordak x B5141-6 (Lenape)	1978
Belchip	Wauseon x B5141-6 (Lenape)	1979
Rosa	Wauseon x J171-8	1981
Conestoga	G6652 x G7063	1982
Agassiz	MN321.64-11 x MN305.64-10	1983
Sunrise	Wauseon x B6563-2	1985
Kanona	Peconic x GN bulk pollen	1988
Gemchip	BR5960-9 x ND5737-3	1989
Allegany	M297-17 x GN bulk pollen	1989
Norwis	RD289-18 x Monona	1990
Mainechip	AF186-2 x AF84-4	1991
Spartan Pearl	Atlantic x MS709	1991
Snowden	B5141-6 (Lenape) x Wischip	1992
Chipeta	WNC612-13 x Wischip	1993
ND860-2	ND78-3 x ND9583-1	1996 ?
NDO1496-1	ND292-1 x A77268-4	1997 ?
NDA2031-2	Rosa x ND413-4	1997 ?

[1]Data taken from Chase (1992).
[2]Dates followed by a question mark indicate a projected release date of each unreleased breeding selection.

weather conditions delayed planting of the Blackfoot trial. Seed tubers of some cultivars developed Fusarium dry rot resulting in reduced stands and yields. Consequently, the Blackfoot trial data were included in the quality evaluations but excluded from the analysis for yield.

Chip quality evaluations included three separate five-tuber samples from each plot. Following a three-week cooling and curing period, one of the three samples was stored at 10 C, one at 4.4 C, and the other at 4.4 C followed by a three week reconditioning period at 15-18 C. The entire storage period, excluding reconditioning, was 3.5 months.

After storage, tubers were cut longitudinally in half. One tuber half was used for cooking tests from which three chips were sliced, washed in cool water, then fried at 175 C until bubbling ceased. The chips were inspected for defects, and the presence of any defect, regardless of size or severity was considered sufficient reason to remove a chip from defect-free status. Finally, the chips were measured for color using an Agtron (M-400-A). This older model of Agtron produces relatively low chip color readings compared to newer machines and a reading of 35 or above would be considered acceptable based on current industry standards. The second half of each tuber was diced, frozen in liquid nitrogen, then freeze-dried. Tuber solids were determined by weighing the diced tubers before freezing and again after freeze-drying. The dried tissue was ground through a 40-mesh screen and analyzed for reducing sugar and sucrose content using a YSI, model 2700 (Yellow Springs Instrument Co., Yellow Springs, OH). Sugars were reported as a percent of fresh weight.

There was some concern that the delayed planting at Blackfoot would impact tuber quality, making the data less reliable. To see if this was the case, each trial was analyzed separately, and means and variances of the Blackfoot trial compared with those from the Aberdeen trials. For every variable, except chip defects, tubers from Blackfoot had similar or better quality than those from Aberdeen. Homogeneity of variances among the three trials were verified for each variable. This allowed data from the three trials to be combined and analyzed using ANOVA. Due to the reduced stands in some plots at Blackfoot, yield data were analyzed for the two Aberdeen trials only. Means separations were made using LSD. Correlations were computed to measure the relationship among some of the chip color and sugar variables. Linear regression analysis was used to measure the rate of breeding progress for the tuber characteristics that are important to chip quality.

RESULTS AND DISCUSSION

Highly significant (p≤0.01) differences existed among cultivars for total yield, U.S. No. 1 yield, tuber solids, chip color, percent of defect-free chips, reducing sugars, and sucrose. Cultivar x trial interactions were present for all variables except chip color following storage at 10 C, indicating a significant genotype x environment (GxE) variance component. Explanation of these interactions was beyond the scope of the current paper and were not explored further.

Yields of the cultivars ranged from 64.2 t/ha for Mirton Pearl to 25.1 t/ha for ND860-2 (Table 2). Rank of the cultivars for U.S. No. 1 tuber yield generally was the same as for total yield. The design of the experiment, with its narrow range of environmental conditions, did not allow meaningful conclusions to be drawn concerning breeding progress for yield. Yield is a trait that is subject to large GxE interactions (Vermeer, 1990). Cultivar adaptation had a strong impact on which cultivars performed well. In the environment where the experiment was conducted, later maturing cultivars, and those with resistance to early dying, had highest yields. Early maturing cultivars such as Haig, Superior, Conestoga, and ND860-2 had lower yields. The relationship between yield and environment in these trials may not be consistent with those found in other areas in North America and so, no conclusions were drawn about breeding progress for yield.

The GxE interactions of tuber solids and sugar content have been shown to be smaller than for yield (Storey and Davies, 1992; Vermeer, 1990), allowing general conclusions about breeding progress to be made for these traits. The same was assumed for chip color because it is closely associated with reducing sugar content. The genetic stability of chip defect score has not been studied so an unsubstantiated assumption was made that it is also stable enough to allow general conclusions to be made.

Trends over the release period represented by the cultivars in this study were shown by graphing chip characteristics from the oldest to the newest. Tuber solids increased slightly from 1876 until the present (Figure 1). The cultivars released prior to 1960 ranged from 19.9 (Teton) to 22.9% (Menominee). The cultivars released since 1980 ranged from 21.2 (Norwis) to 25.6% (Mainechip). The most prominent feature of the change in tuber solids is not the overall trend, but the spikes that occurred between 1967 and 1978, and again after 1990. The initial spike corresponds with the release of the first cultivars specifically bred for chip production. The second corresponds with recent industry interest in using cultivars high in solids for the purpose of reducing oil con-

TABLE 2.—*Total and U.S. No. 1 yields of forty-four cultivars historically used and/or bred for chip production. The cultivars are ranked according to release date.*

Cultivar	Total Yield[1]	U.S. No. 1 Yield[1]
	- t/ha -	- t/ha -
Irish Cobbler	41.0	27.7
Russet Burbank	52.2	34.6
Katahdin	57.0	47.9
Chippewa	48.3	39.8
Houma	51.2	39.1
Sebago	41.0	25.5
Erie	41.9	29.7
Menominee	45.9	35.7
Teton	49.4	39.8
Kennebec	58.2	39.2
Yampa	54.8	44.5
Pungo	49.3	40.3
Merrimack	34.7	25.2
Saco	55.4	41.9
Plymouth	42.9	35.6
Tawa	42.4	33.5
Haig	35.2	23.7
Superior	32.4	25.9
LaChipper	45.4	36.6
Monona	41.2	35.7
Lenape (B5141-6)	45.0	35.5
Norchip	41.9	25.8
Shurchip	38.9	30.4
Raritan	38.2	30.9
Mirton Pearl	64.2	55.6
Atlantic	44.8	35.8
Tobique	42.9	34.6
Trent	45.1	40.0
Belchip	44.7	36.5
Rosa	53.2	39.0
Conestoga	33.5	25.6
Agassiz	33.7	17.0
Sunrise	33.2	24.8
Kanona	49.7	43.3
Gemchip	54.1	43.1
Allegany	55.9	48.4
Norwis	42.0	36.4
Mainechip	35.6	22.3
Spartan Pearl	45.1	38.5
Snowden	49.7	37.4
Chipeta	57.0	47.7
ND860-2	25.1	9.0
NDO1496-1	46.7	36.4
NDA2031-2	57.5	43.2
LSD (0.05)	4.22	4.33

[1]Yields were averaged over two trials grown in 1994 and 1995 at Aberdeen, Idaho.

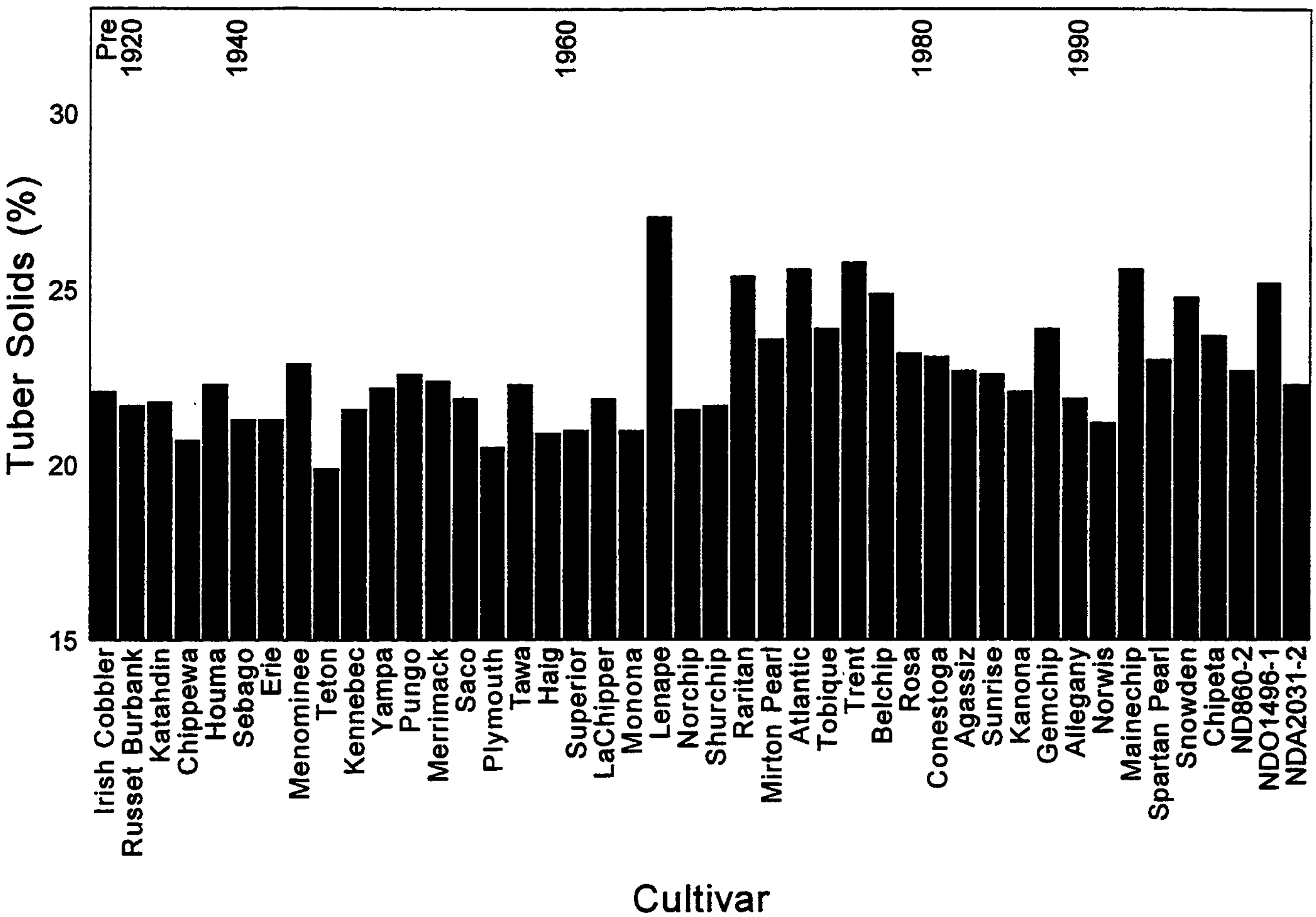

FIGURE 1
Tuber solids of forty-four cultivars historically used and/or bred for chip production. The cultivars are listed chronologically by release date, and numbers at the top of the graph reflect the year of release. Tubers were stored for 3.5 months at 4.4C, 10C, or 4.4C followed by reconditioning at 15-18C prior to evaluation.

tent of chips. Lenape is a cultivar that was released in 1967 and subsequently withdrawn from commerce due to a high level of glycoalkaloids in the tubers. Lenape was the first of the high solids cultivars and was the highest in this study (27.1%).

Trends for potato chip color and reducing sugar content were more consistent and pronounced than for tuber solids (Figures 2 and 3). There appears to have been a steady improvement as indicated by lighter colored chips and lower reducing sugars. This trend was consistent regardless of the storage treatment. Correlations among the storage treatments were highly significant ($p \leq 0.01$) for both Agtron readings (r values from 0.71 to 0.78) and reducing sugars (r values from 0.62 to 0.74). Agtron readings for each variety were lowest out of 4.4 C storage, highest from 10 C storage, and in between for the reconditioned tubers.

Snowden, ND860-2, NDO1496-1, and NDA2031-2 are cultivars resulting from recent efforts to develop potatoes that will make acceptable chips after being stored at cold temperatures. These three unreleased selections were the lowest in reducing sugars and best in chip color of the 44 cultivars. However, these cold chippers did not exhibit unusual breakthrough characteristics, but rather were part of the consistent trend toward the development of cultivars with lower reducing sugars and better chip color. The most recently released cultivars and unreleased selections were capable of producing chip color and sugar levels out of 4.4 C storage that were similar to those produced by the oldest cultivars out of 10 C. From an industry standpoint, this is a significant improvement. Some cultivars tended to have agtron readings and reducing sugar levels that were considerably above or below the cultivars released in the same era. For example, Sebago, Lenape, and Atlantic had lower reducing sugars and better chip color than did concurrent cultivars. Pungo and Sunrise were worse for both traits than companion cultivars.

Sucrose content of the cultivars did not show the same decreasing trend in relation to release date that was evident for reducing sugar content (Table 3). Selection for better chip color, the common breeding practice, apparently has not lowered sucrose content as it has reducing sugars.

The last trait considered was the percent of defect-free chips produced by each cultivar. Defects were caused by several factors, including mechanical injury, hollow heart, heat necrosis, sugar-ends, and the presence of disease organisms. There was a general trend for a greater percentage of defect-free chips to be associated with later release dates (Figure 4). However, there was considerable variability among the cultivars within each era. Five of the six cultivars with highest percentage of defect-free chips were the most recently released. These cultivars were developed or released during a period of time when there was industry pressure to improve chip appearance. Spartan Pearl was an exception to the recent trend, being the sixth newest cultivar and among the worst for defects with only 9 percent of its chips being defect free chips. Lenape was similar to the newest cultivars for percent defect-free. If Lenape and Atlantic were not considered, the improvement in the ability to produce defect-free chips was shown to be a very recent phenomenon.

The rate of breeding progress, as measured using regression analysis, is presented in Table 4. Rate of progress was measured by computing the regression coefficient (regression line slope) for three periods of time. The first covered 121 years and included the entire span of release dates for the forty-four cultivars in the trial (1876-1997). The cultivars were then divided into two groups, those released prior to dedicated chip cultivar breeding (1876-1960), and those released afterward (1961-1997), and breeding progress computed for each period.

Over the entire 121 year cultivar release period represented in the study, all evaluated chip quality characteristics expressed a significant ($p \leq 0.05$) rate of breeding progress. On average, tuber solids increased 0.025% per year, reducing sugars decreased 0.0013 to 0.0031% FW per year depending on the storage environment; chip color increased 0.15 to 0.18 agtron units per year depending on the storage environment; and the percentage of defect-free chips increased 0.23% per year. This confirms the conclusions reached by a visual inspection of Figures 1-4, that potato breeders have made significant progress in improving important chip quality traits.

TABLE 3.—*Sucrose content of 44 cultivars historically used and/or bred for chip production. The cultivars are ranked according to release date.*

Cultivar	Sucrose 4.4 C storage[1]	Sucrose 10 C storage[1]	Sucrose Reconditioned[1]
	- % FW -	- % FW -	- % FW -
Irish Cobbler	0.25	0.12	0.11
Russet Burbank	0.22	0.12	0.11
Katahdin	0.39	0.14	0.11
Chippewa	0.31	0.13	0.12
Houma	0.21	0.10	0.08
Sebago	0.44	0.09	0.10
Erie	0.29	0.12	0.12
Menominee	0.26	0.15	0.13
Teton	0.25	0.08	0.10
Kennebec	0.21	0.08	0.08
Yampa	0.32	0.11	0.14
Pungo	0.37	0.17	0.15
Merrimack	0.23	0.13	0.13
Saco	0.23	0.11	0.09
Plymouth	0.24	0.11	0.09
Tawa	0.38	0.12	0.11
Haig	0.17	0.11	0.11
Superior	0.15	0.08	0.08
LaChipper	0.26	0.11	0.13
Monona	0.32	0.07	0.09
Lenape (B5141-6)	0.30	0.14	0.12
Norchip	0.47	0.09	0.10
Shurchip	0.25	0.13	0.12
Raritan	0.29	0.15	0.12
Mirton Pearl	0.30	0.18	0.15
Atlantic	0.34	0.11	0.10
Tobique	0.26	0.14	0.13
Trent	0.64	0.13	0.20
Belchip	0.37	0.10	0.13
Rosa	0.32	0.15	0.15
Conestoga	0.52	0.11	0.14
Agassiz	0.50	0.14	0.20
Sunrise	0.34	0.13	0.13
Kanona	0.27	0.10	0.12
Gemchip	0.21	0.11	0.12
Allegany	0.21	0.09	0.10
Norwis	0.60	0.10	0.19
Mainechip	0.44	0.13	0.13
Spartan Pearl	0.68	0.13	0.18
Snowden	0.26	0.08	0.07
Chipeta	0.42	0.08	0.14
ND860-2	0.21	0.06	0.06
NDO1496-1	0.21	0.07	0.08
NDA2031-2	0.13	0.07	0.06
LSD (0.05)	0.056	0.015	0.022

[1]Sucrose content is reported as a percent of fresh weight (FW) and was averaged over three trials grown in 1994 and 1995 at Aberdeen and Blackfoot, Idaho. Tubers were stored for 3 months at 4.4 C, 10 C or 4.4 C followed by reconditioning for three weeks at 15-18 C.

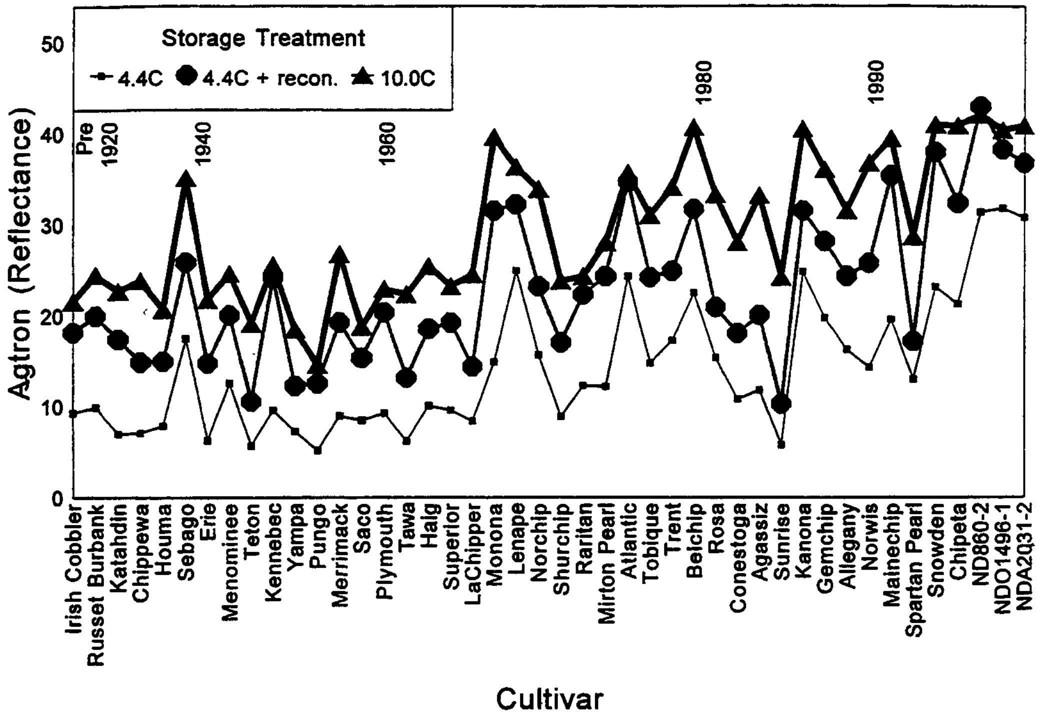

FIGURE 2

Agtron values (% reflectance) indicating color of chips from tubers of forty-four cultivars historically used and/or bred for chip production. The cultivars are listed chronologically by release date, and numbers at the top of the graph reflect the year of release. Tubers were stored for 3.5 months at 4.4C, 10C, or 4.4C followed by reconditioning at 15-18C prior to evaluation.

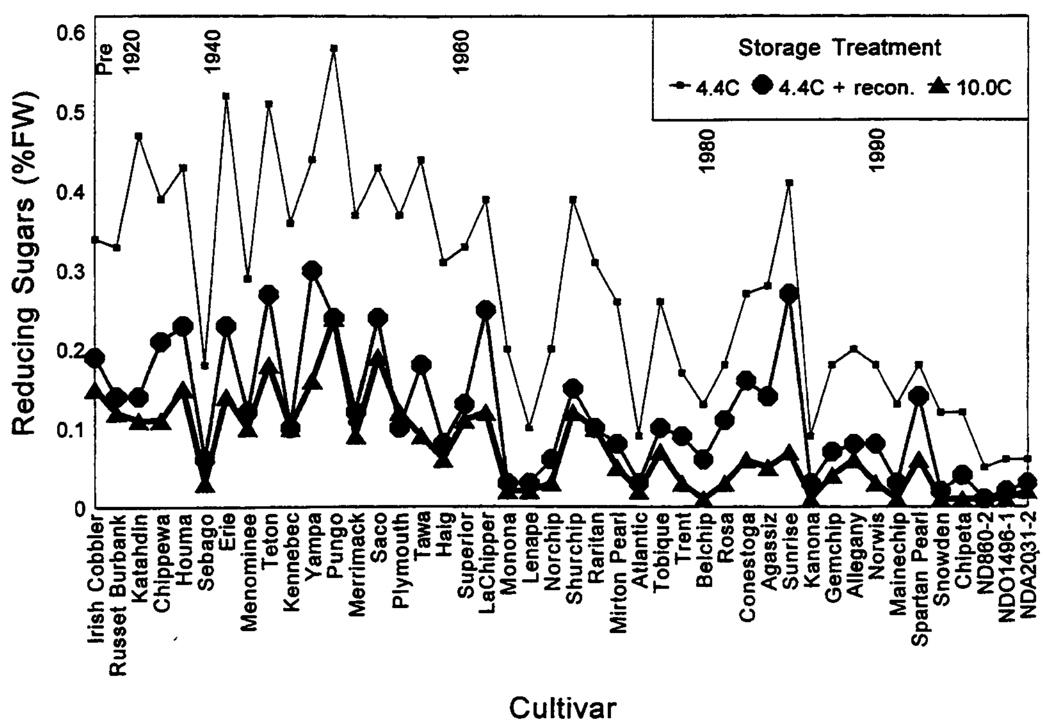

FIGURE 3

Reducing sugar content of tubers from forty-four cultivars historically used and/or bred for chip production. The cultivars are listed chronologically by release date, and numbers at the top of the graph reflect the year of release. Tubers were stored for 3.5 months at 4.4C, 10C, or 4.4C followed by reconditioning at 15-18C prior to evaluation.

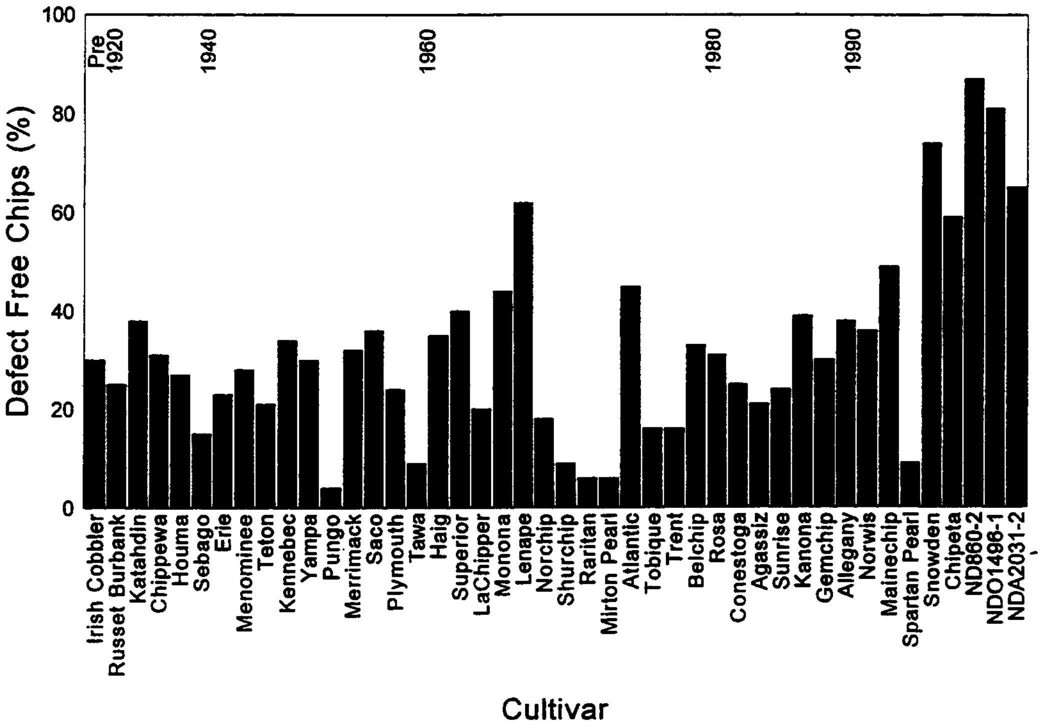

FIGURE 4
Percent of defect free chips from tubers of forty-four cultivars used and/or bred for chip production. The cultivars are listed chronologically by release date, and the numbers at the top of the graph reflect the year of release.

TABLE 4.—*Average annual breeding progress for important chipping characteristics as derived from linear regression.*

Characteristic	Units	Breeding Progress in Units Per Year[1]		
		1876-present	1876-1960	1960-present
Tuber Solids	% D.M.	0.025**	-0.02ns	0.018ns
Reducing Sugars (4.4 C)	% F.W.	-0.0031**	0.0009ns	-0.0054**
Reducing Sugars (Recond.)	% F.W.	-0.0014**	-0.0001ns	-0.0020ns
Reducing Sugars (10.0 C)	% F.W.	-0.0013**	-0.0001ns	-0.0017**
Chip Color (4.4C)	% reflectance	0.15**	-0.02ns	0.35**
Chip Color (Recond.)	% reflectance	0.16**	-0.03ns	0.34*
Chip Color (10.0C)	% reflectance	0.18**	-0.01ns	0.32**
Defects	% of chips free	0.23*	-0.04ns	1.02**

[1]Values are linear regression coefficients and are followed by symbols indicating whether each slope is significant at $p \leq 0.01$ (**), $p \leq 0.05$ (*), or not significantly (ns) different from zero.

The rate of breeding progress for the early breeding period (before 1960) was markedly different from that for the later period (Table 4). Regression coefficients for the early period were near zero and not significant ($p \leq 0.05$) for all characteristics. Virtually no improvement in chip quality traits was evident during the period 1876 to 1960. The improvement documented was achieved during the post-1960 period. This was not entirely unexpected because very little attention was given by breeders to chip quality prior to 1960.

Unlike most other characteristics, tuber solids showed significant improvement over the entire 121 year period, but not within either of the shorter periods. This was a result of the sudden increase, and subsequent flattening of the progress curve that occurred between 1960 and 1970 as seen in Figure 1. Unlike the other traits, tuber solids did not continue to show progress after initial improvement at the beginning of the dedicated chip cultivar breeding period. However, there was significant improvement in tuber solids for the cultivars released after 1960 in comparison to those released before. The early cultivars averaged 21.6% tuber solids while the later ones averaged 23.6%, a difference shown to be significant (p≤0.05) using a simple t-test.

The level of reducing sugars following reconditioning did not show a significant regression coefficient for the later period, in spite of having a fairly high coefficient value. This was interpreted as being an artifact that was due to the inherent variability in sugar level and chip color that results from the reconditioning process. Reconditioned tubers are more variable from plot to plot, location to location, and cultivar to cultivar than are tubers held at a constant temperature. This led to a high sum of squares and a nonsignificant regression coefficient even though the numerical value of the coefficient was higher than for reducing sugars of tubers stored at 10 C. Based on this information, and the fact that chip color for reconditioned tubers did show significant improvement, it was determined that breeding progress did occur for this trait.

This study provided one unexpected insight into the development of chipping cultivars in this century, that being the emergence of evidence that the release of Lenape marked a major advance in chipping quality. Lenape was substantially better with respect to chip quality than any cultivar released previously and remained better than many that came after. Its withdrawal from commerce was unfortunate, but its influence continues. Twelve of the 23 cultivars that were a part of the study and released after Lenape, have Lenape in their ancestry, including the cultivars Atlantic, Gemchip, Mainechip, Snowden, Chipeta, ND860-2, and NDO1496-1, all of which have excellent chipping characteristics. Trent, Belchip, Conestoga, Sunrise, and Spartan Pearl also have Lenape parentage. Snowden, the most rapidly expanding cultivar in production during the time this study was done, has Lenape as one parent. It is apparent that the development of Lenape was responsible for a large portion of the progress that has been made for improved chipping quality since 1970. If Lenape and its twelve progeny are removed from the tuber solids graph (Figure 1), any trend for improvement disappears. Deletion of the same thirteen cultivars from the reducing sugar and chip color graphs (Figures 2 and 3) does not completely eliminate any trend for improvement, but most of the superior cultivars with respect to these traits would be removed.

Potato breeders in North America have been very successful in improving chip quality in potatoes. This is evidenced by a slight improvement over time in cultivars for tuber solids, significant and large improvements for reducing sugar content and chip color, and a recent improvement in cultivars with respect to their ability to produce defect-free chips. The rate of improvement for these traits does not appear to be diminishing. If current trends continue, breeders should expect additional improvement for chip color, reducing sugar content, and defect-free chips. Future trends in tuber solids are less predictable. Because higher solids are not consistently considered advantageous by the chipping industry, future changes may be erratic.

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